The Relation between the Stellar Structure of Red Giants and The Formation and Evolution of Gas Giant Planet

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Introduction

The behavior of two components gravitating systems with a core component at center and an envelope component extending around the core component, so-called core-halo structure, is important and can be applied in many astrophysical problems.

Examples of two components system

- ☐ Globular clusters
- ☐ Clusters of galaxies
- ☐ Stellar structure of red giant phase (Core-Halo structure)

◆ Structure of Red giant star

Stellar structure of Red giants phase is well described by a double–polytrop model (Fujimoto & Tomisaka 1992).

◆ Gas giant planet have core-halo structure

Planets formed by Core accretion have a structure which is composed of a solid core made of rock or ice and a gaseous envelope around rocky or icy core.

◆ Motivations of this study

According to Previous study (Mizuno 1980:Bodenheimer&Pollack 1986), proto-planet causes runaway accretion and becomes gas giant planet as the Jupiter. On the other hand, star at Red giant phase is stable though both have Core-Halo structure.
What will the cause of the difference be ?

Model and assumption

✓Double polytrop model

applied to gas giant planets formation boundary condition

☐ Equations

$$\frac{1}{(\rho_{core}+\rho_{gas})}\frac{d(P_{core}+P_{gas})}{dr}=-\frac{G(M_{core}+M_{gas})}{r^2}$$

Hydrostatic equation with two components

Each component is assumed to be hydrostatic equilibrium as the following

$$\frac{1}{\rho_{core}}\frac{dP_{core}}{dr}=-\frac{G(M_{core}+M_{gas})}{r^2}$$

assumed to be uniform density , and to be always hydrostatic equilibrium.

$$\frac{1}{\rho_{gas}}\frac{dP_{gas}}{dr}=-\frac{G(M_{core}+M_{gas})}{r^2}$$

$$\frac{dM}{dr}=4\pi r^2\rho,$$ Continuous equation

$$P=K\rho^{1+1/n},$$ Polytropic relation

$$P=\frac{k}{\mu m_H}\rho T$$ Equation of state (ideal gas)

☐ Outer boundary condition

$$\rho=\rho_{disk},\quad T=T_{disk}$$

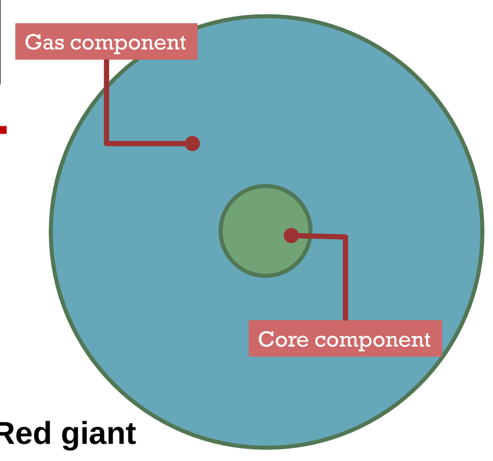
Thermal condition is fixed as disk condition
Because envelope is assumed to be equilibrium with disk gas

$$R=\min(R_{bondi},R_{hill}),$$

$$R_{bondi}=\frac{GM_p}{c_s^2},\qquad R_{hill}=a_p\left(\frac{M_p}{3(M_p+M_*)}\right)^{1/3}$$

Accretion radius (Bondi radius)

Tidal radius (Hill radius)



✓ stellar boundary condition

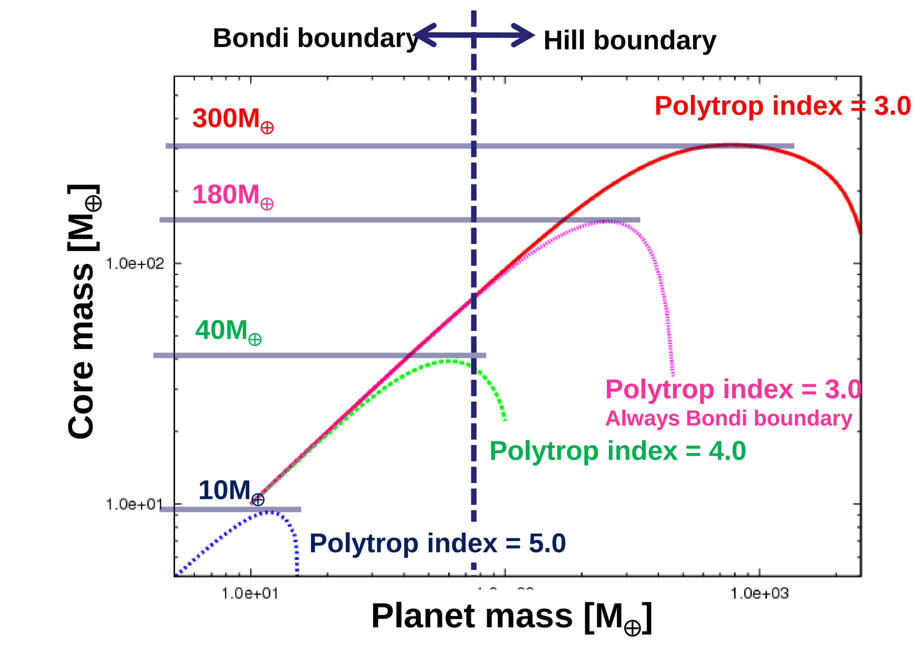
$$P=0,T=0$$

Boundary condition is one of the differences with Red giant and Gas giant planet

Result

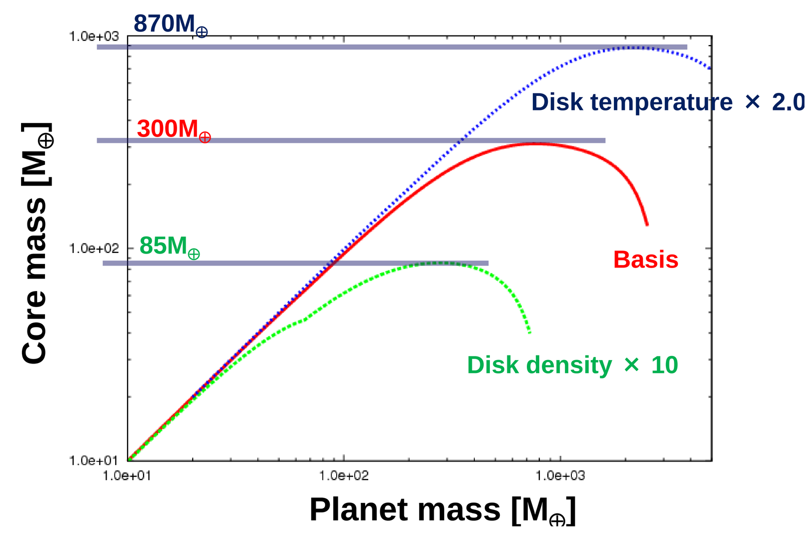
☐ Critical core mass

✓ Dependence of polytrop index



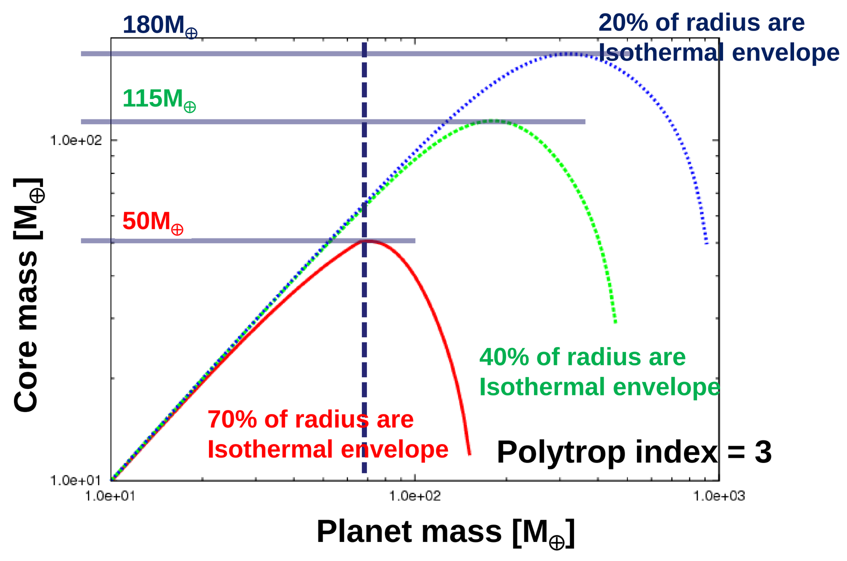
PARAMETER	
disk density (g/cm^3)	5.00E−11
disk temperature (K)	1.50E+02
semi major axis (AU)	5.00E+00
host star mass (M☉)	1.00E+00
core density (g/cm^3)	5.50E+00

✓ Dependence of boundary condition



✓ Connection to isothermal part

A model with planet formation boundary condition have large radius than without core, and have only weak internal energy source . Thus a model should have isothermal structure around surface.



polytrop index	isothermal part	critical core mass (M⊕)	ratio of core mass and planet mass
3.00	no	300	0.38
4.00	no	40	0.66
5.00	no	10	0.78
3.00	70% of radius	50	0.73
3.00	40% of radius	115	0.63
3.00	20% of radius	180	0.52

Characteristic figure of structure such as Red Giants

U and V ,defined as the following, is very useful parameter for studying of structure such as Red giants

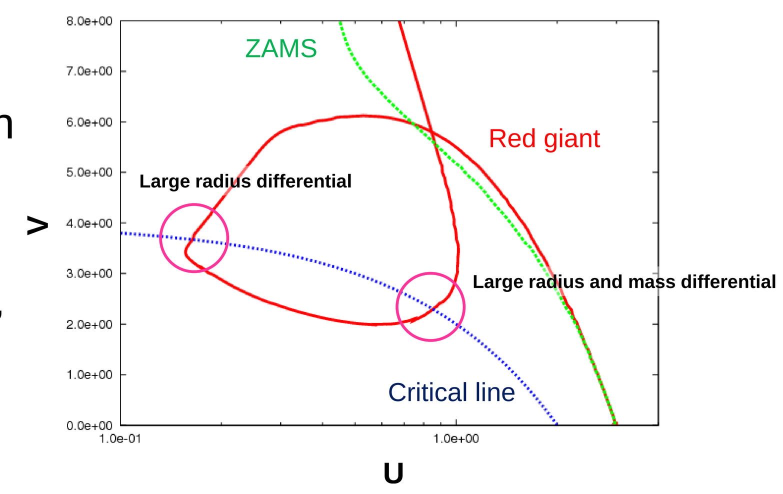
$$U=\frac{d\log M_r}{d\log r}=\frac{3\rho}{\langle\rho\rangle_r},\qquad V=-\frac{d\log P}{d\log r}=\frac{GM_r/r}{P/\rho}$$

Using U and V, structure obtain as the following equation

$$d\log M_r=\frac{U(d\log V-d\log U)}{2U+V-4},\qquad d\log r=\frac{d\log V-d\log U}{2U+V-4}$$

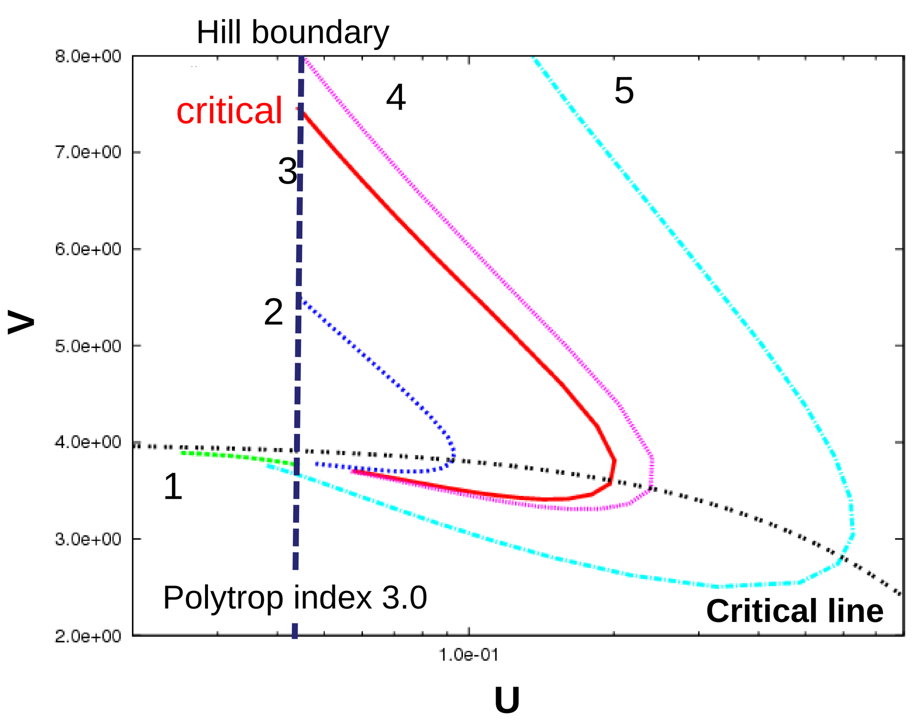
$$2U+V-4=0$$ Critical line : at intersection of this line and structure line, derivative of radius (and mass) is very large.

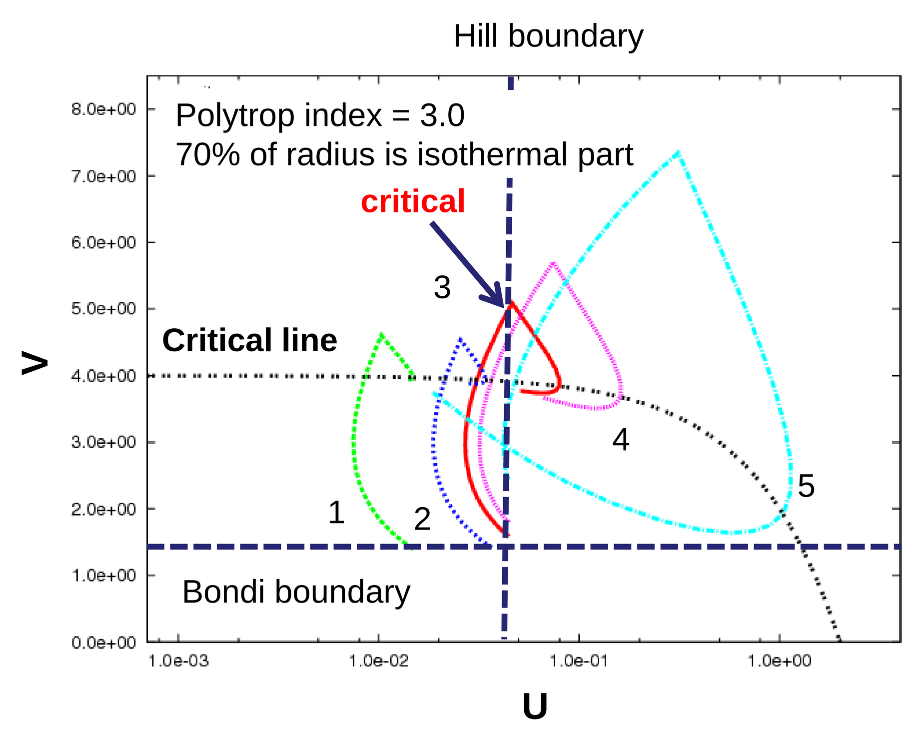
✓ Figure of Red giant star



☐ Envelope structure on UV plane

The bigger the number of subscript is, the larger the mass of model is





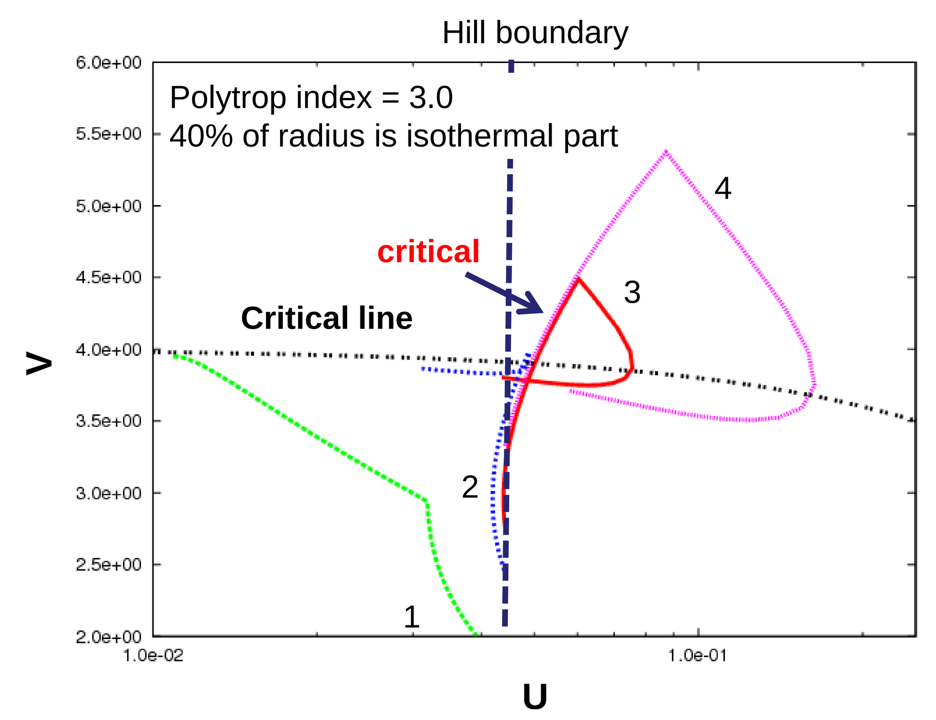
✓Boundary condition on UV plane

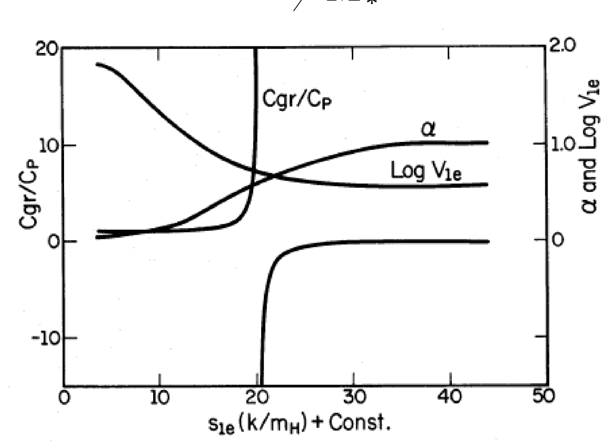
● **Bondi boundary condition**

$$U=4\pi\left(\frac{M_p}{\rho_{surf}}\right)^2\left(\frac{GP_{surf}}{\gamma_{surf}}\right)^3,\qquad V=\gamma_{surf}$$

● **Hill boundary condition**

$$U=\frac{4\pi a_P^3\rho_{surf}}{M_*(1+M_P/M_*)},\qquad V=\frac{GM_p}{a_P}\frac{\rho_{surf}}{P_{surf}}\left(1+M_*/M_P\right)^{1/3}$$





Changes in thermal behavior of gas in the envelopes of white dwarf (Fujimoto, M.Y. 1982,Apj)

Conclusion & Discussion

- ◆ We applied the double polytrop model to the formation and evolution of gas planet.
- ◆ Double polytrop model with planet formation boundary condition have the peak core mass (critical core mass) based planet mass.
- ◆ Structure line have intersection of critical line when model have core mass which is near to critical core mass.
- ◆ V at bottom of envelope of model with over critical core mass is less than it of model with smaller critical core mass
  - ◆ Changes in thermal behavior of gaseous envelope ?